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ACRONYMS AND ABBREVIATIONS

ALARA	as low as is reasonably achievable
CHF	Canister Handling Facility
DTF	Dry Transfer Facility
TEDE	Total Effective Dose Equivalent

1. PURPOSE

The purpose of this design calculation is to estimate radiation doses received by personnel working in the subsurface facility of the repository performing emplacement, maintenance, and retrieval operations under normal conditions. The results of this calculation will be used to support the design of the subsurface facilities and provide occupational dose estimates for the License Application.

2. QUALITY ASSURANCE

This document was prepared in accordance with [AP-3.12Q](#), *Design Calculations and Analyses*. Because the results of this calculation will be used to support the Preclosure Safety Analysis relative to radiological safety of the repository, this document is subject to the requirements of the *Quality Assurance Requirements and Description*, DOE/RW-0333P, document (DOE 2003, [Section 2.2.2](#)).

3. METHOD

The methodology used in this calculation consists of three major elements, including a subsurface facility worker dose assessment, a comparison with applicable occupational dose regulations and criteria, and a discussion of how uncertainties, conservative inputs, and bounding assumptions impact the results of this calculation.

The dose assessment involves calculations of annual individual and collective doses to subsurface repository workers. These occupational doses are defined as the Total Effective Dose Equivalent (TEDE) received by workers involved in subsurface facility operations. The TEDE consists of the deep-dose equivalent from direct exposure to contained sources and airborne radionuclides (submersion), summed to the committed effective dose equivalent from inhalation of airborne radionuclides.

During emplacement and retrieval operations, the sealed waste packages are either enclosed by the shielded waste package transporter or are transferred to or from the waste package transporter downstream (based on the ventilation flow direction in the subsurface facility) from any subsurface workers. Therefore, any airborne release of radionuclides from the surface of waste packages being emplaced or retrieved would not contribute directly to the inhalation dose to subsurface workers performing these operations, and only external doses are considered in this calculation.

The dose assessment is performed by job function or a worker group using the time-motion inputs and dose rates calculated at various worker locations. Two major worker groups are addressed in this calculation: waste package emplacement and retrieval personnel and subsurface maintenance personnel.

For workers involved in the subsurface emplacement of waste packages, operations begin at the time the waste package is loaded onto the transporter at the Dry Transfer Facility (DTF) or

Canister Handling Facility (CHF). During retrieval, operations begin when an empty transporter leaves the DTF or CHF to retrieve an emplaced waste package. Each emplacement operation ends when the operators return the empty transporter to the surface to pick up a new waste package; each retrieval operation ends when the transporter delivers a waste package to the receiving surface facility. Initial calculations are made on a per-waste-package basis using an Excel spreadsheet. The resulting individual or collective doses are then multiplied by the maximum number of waste packages transferred between surface and subsurface facilities per year. Individual worker dose assessments take into account the possibility of multiple shifts per day so that total time worked per day does not exceed eight hours for any given worker. The equation used to calculate the annual individual dose to a waste package emplacement and retrieval worker is:

$$ED_g = \sum_i (EDR_{i,g} \times T_i) \times WP_g \quad (\text{Eq. 1})$$

where:

- ED_g = External dose to a worker in group g (mrem/yr)
- $EDR_{i,g}$ = External dose rate at location i to a worker in group g (mrem/hr)
- T_i = Duration of the exposure at location i per transfer operation (hr/transfer)
- WP_g = Annual number of waste package transfers involving a worker in group g (transfers/yr)

To assess the individual dose to maintenance workers, [Equation 1](#) is slightly modified as follows:

$$ED_g = \sum_i (EDR_{i,g} \times T_i) \times M_g \quad (\text{Eq. 2})$$

where:

- T_i = Duration of the exposure at location i per maintenance operation (hr/operation)
- M_g = Annual number of maintenance operations involving a worker in group g (operations/yr)

The collective dose for a group of workers explicitly accounts for multiple shifts (e.g., two waste package transfers per day using two work crews, per [Assumption 4.2.11](#)) by summing the individual doses of all workers in group g as follows:

$$CED_g = \sum_g (P_g \times ED_g) / 1000 \quad (\text{Eq. 3})$$

where:

- CED_g = Collective annual dose to worker group g (person-rem/yr)
- P_g = Number of workers in group g (person)
- 1000 = Unit conversion factor (mrem/rem)

[Equation 3](#) applies to both emplacement/retrieval workers and maintenance workers for calculating the collective dose.

3.1 WASTE PACKAGE EMPLACEMENT AND RETRIEVAL OPERATIONS

The following considerations apply primarily to calculating doses to subsurface emplacement and retrieval workers. Some of these methodologies also apply to calculating doses to subsurface maintenance workers, as noted in [Section 3.2](#).

The dose rates at various locations of interest will primarily be due to the gamma and neutron radiation emitted from the waste package inside the shielded transporter or from scattered radiation leaving the emplacement drifts along the subsurface transport route. The radiation field to which operators are exposed from the waste package inside the transporter is assumed to be constant for the duration of the transport from the surface until the time the waste package transporter moves into an emplacement drift turnout ([Assumption 4.2.4](#)). There will be localized radiation fields at the turnouts along the waste package transfer route. These locations with higher dose rates will occur at the intersections between the main drift and each filled emplacement drift ([Assumption 4.2.5](#)). Therefore, the dose rate in the main drift along the transfer route will vary, peaking whenever the transporter approaches the midpoint of each emplacement drift turnout and dropping shortly after the transporter passes the turnout. Thus, in addition to the continuous radiation field from the waste package in the shielded transporter, the operators are subject to a varying exposure rate along the transfer route. When returning an empty transporter to its point of origin, operators are only exposed to this varying exposure rate. The average dose rate in both directions along the waste package emplacement or retrieval route between the first and last emplacement drift passed by the transporter is calculated simply as a distance-weighted average dose rate:

$$EDR_{Av} = (EDR_{TO} \times N_{ED} \times D_{TO})/D_{ED} + \{EDR_{Main} \times [D_{ED} - (N_{ED} \times D_{TO})]\}/D_{ED} \quad (\text{Eq. 4})$$

where:

- EDR_{Av} = Average dose rate along the emplacement route (mrem/hr)
- EDR_{TO} = Average dose rate in the vicinity of an emplacement drift turnout (mrem/hr)
- EDR_{Main} = Average dose rate away from an emplacement drift turnout (mrem/hr)
- D_{TO} = Effective width of an emplacement drift turnout (m)
- D_{ED} = Distance between the first and last emplacement drift along the route (m)
- N_{ED} = Number of emplacement drift turnouts passed by a transporter

[Equation 4](#) applies to all emplacement routes, including those in which the turnouts are located on both sides of the track. Routes through Panels 1, 2, and 4 have turnouts on one side of the track (BSC 2003a, Figures 6, 7, and 9). However, turnouts in Panel 3 are located on both sides of the track (BSC 2003a, Figure 8), and are offset so that west and east turnout openings are not directly across from one another.

The dose rate in the vicinity of an emplacement drift turnout is a function of location along the intersection with the access main. [Figure 1](#) shows how this dose may vary as the transporter approaches and leaves a turnout area. Note that [Figure 1](#) is used only to illustrate the possible dose-rate profile in the vicinity of a typical drift turnout. The numerical values shown in [Figure 1](#) are not used as direct inputs to this calculation.

If dose rates at two or more points along this intersection have been calculated, then a distance weighted average dose rate can also be calculated for use as input to [Equation 4](#). [Equation 5](#) shows how such a distance-weighted average dose rate can be calculated for the four dose points shown in [Figure 1](#) along the main access drift in the vicinity of a turnout.

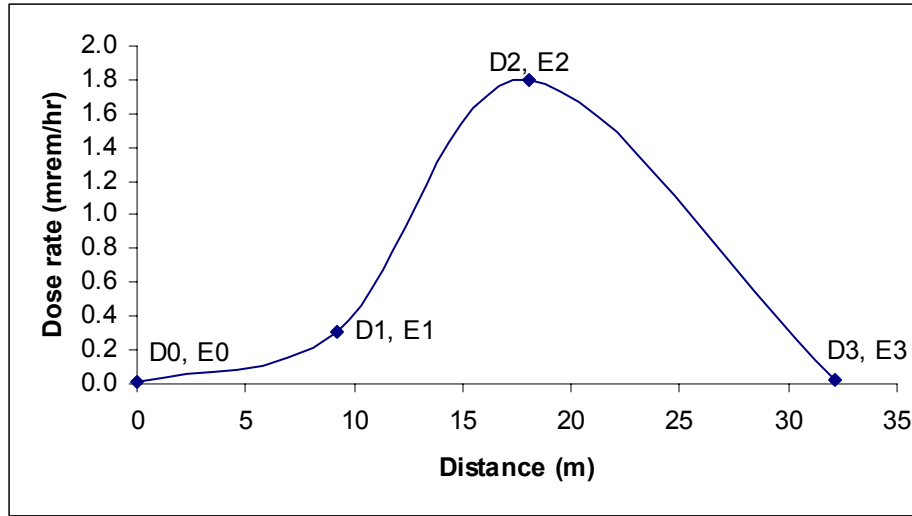


Figure 1. Hypothetical Dose-Rate Profile in the Vicinity of an Emplacement Drift Turnout

$$EDR_{TO} = \sum_{i=1,2,3} \{[(E_{i-1} + E_i)/2] \times (D_i - D_{i-1})\} / D_3 \quad (\text{Eq. 5})$$

where:

E_i = Dose rate at exposure point i (mrem/hr), where $i = 1, 2, 3$

D_i = Distance from first exposure point (E_0), where $D_0 = 0$ (m) and $i = 1, 2, 3$

While [Equations 4](#) and [5](#) represent simplifications of the actual exposure conditions along the transport route, they are adequate for purposes of this calculation because the locomotive or support equipment is assumed to travel at a constant speed along this route ([Assumptions 4.2.9](#) and [4.2.10](#), respectively). This averaging approach is also adequate and consistent with the requirement to calculate the total dose to individual workers or group of workers over a full year.

The time spent by workers traveling in each direction between the first and last emplacement drift passed by the transporter is calculated as follows:

$$T_{TO} = D_{ED} / (1610 \times S_T) \quad (\text{Eq. 6})$$

where:

- T_{TO} = Transporter travel time in the emplacement area (hr)
- S_T = Transporter speed (mph)
- 1610 = Conversion factor (m/mi)

The time for the transporter to travel between the surface facilities and subsurface emplacement area is calculated as follows:

$$T_{S-SS} = D_{S-SS} / (1610 \times S_T) \quad (\text{Eq. 7})$$

where:

- T_{S-SS} = Transporter travel time between the surface and subsurface (hr)
- D_{S-SS} = Distance between the surface facility and subsurface emplacement area (m)

3.2 SUBSURFACE MAINTENANCE OPERATIONS

As indicated in [Section 3.1](#), some of the above considerations extend to the calculation of doses to subsurface maintenance workers, including the equations used to calculate time and distance inside the access main. Not all of the subsurface areas will be accessible to maintenance personnel or require maintenance. The rationale for excluding certain areas from consideration, as well as the methodology used to analyze all other maintenance operations and their radiological impacts, is summarized below.

Since maintenance workers will not be transporting a waste package to or from the subsurface, the only areas of concern for maintenance worker radiation doses are the intersections between the turnouts and access mains. Equipment that requires maintenance, such as the electrical or communications equipment, will be placed outside the intersection of the mains and turnouts to reduce the exposure to personnel.

The overhead gantry and antennae in the turnouts (inside the emplacement drift doors) are only required for emplacement, so there will be no need to maintain these items after emplacement. While they could be operational after emplacement is completed, any operation that takes place in the turnout after emplacement will not rely on them being present or operational. These items can be replaced remotely if it is determined that retrieval is required. Therefore, there is to be no scheduled maintenance on the inside of the emplacement drift door.

There is no scheduled maintenance for the exhaust mains and these areas will be limited to remote observations. Any non-routine maintenance in the turnout or exhaust main will be handled similarly to the emplacement drift maintenance. This will involve a campaign to isolate the area from the radiation source through temporary shielding or potentially moving waste packages (as required) and securing the area before work begins. These openings will be set up to eliminate potential maintenance items. For example, the exhaust main is not expected to have rail access because there is no requirement for rail in the exhaust, and the rail could require

maintenance. Dose impacts from such non-routine maintenance campaigns are excluded from this calculation.

It is assumed that various maintenance crews will perform different maintenance functions on different systems, including ventilation, electrical, mechanical (rail), and ground control ([Assumption 4.2.12](#)). For example, the ground control inspector will not maintain the ventilation louver.

As specified in more detail in [Assumption 4.2.12](#), the ventilation maintenance crew is expected to have three workers: one worker will be responsible for the controls and calibration of controls, and two workers will remove and install louvers. The rail (mechanical) maintenance crew is expected to have three workers: one worker will be an equipment operator and two workers will remove and install rail. The electrical and ground control maintenance crews are each expected to have one worker who will perform inspections.

4. DESIGN INPUT

4.1 DESIGN CRITERIA

The following design parameters are either used directly to calculate worker doses or form the basis for assumptions listed in [Section 4.2](#).

4.1.1 Sequence of Operations – Waste Emplacement

The *Emplacement and Retrieval System Description Document* (BSC 2003b, Section 4.1.4.1.2, pp. [99](#), [100](#), [101](#)) describes the waste package transportation and emplacement sequence of operations for a typical emplacement drift. This forms the basis for determining the number of operators, radiation fields to which they will be exposed, and duration of their exposures. The waste emplacement sequence of operations is detailed below:

1. At the Heavy Equipment Maintenance Building, a single emplacement pallet is loaded onto the movable bedplate of the transporter. The bedplate with the pallet is then pulled into the shielded enclosure of the transporter. The primary locomotive moves the transporter into the load-out area of the DTF or CHF.
2. Once in the load-out area, the waste package transporter shield doors are opened and the emplacement pallet is pushed out of the shielded portion onto the transfer deck portion of the transporter.
3. The emplacement pallet is lifted off the waste package transporter for loading a waste package onto the pallet.
4. A single waste package is placed on the emplacement pallet and then placed back onto the transfer deck of the waste package transporter.
5. The emplacement pallet and waste package are pulled into the shielded enclosure of the transporter.

6. The shielding doors are closed. The primary locomotive pulls the loaded transporter away from the DTF or CHF docking area. [Note: this step is further broken down into two steps in Assumptions [4.2.1](#) and [4.2.2](#). Only the second part of this step would expose workers to the radiation field of the transporter.]
7. Stopping at a track turnout outside the DTF or CHF, a secondary locomotive is coupled to the transporter.
8. The entire train is moved through turnouts on the surface to ensure that the waste package transporter is correctly oriented for entry into the emplacement drift turnout.
9. Both locomotives, one in front and one behind, move the loaded transporter into the subsurface facilities.
10. The train stops near the predetermined emplacement drift turnout.
11. The secondary locomotive in front of the transporter is uncoupled by remote control operators and moved to a standby location in the main drift.
12. The locomotive controls are turned over to remote control operators in the central control center at the surface. The on-board locomotive operators then move to a designated subsurface location near the emplacement drift.
13. The ventilation isolation doors at the entrance to the emplacement drift turnout are opened, and the rail switch is thrown to the turnout side.
14. The primary locomotive behind the transporter remotely moves the transporter into the turnout and stops before reaching the emplacement drift docking area.
15. The ventilation isolation doors are closed after the waste package transporter passes.
16. The shielded transporter enclosure doors are fully opened from the central control center.
17. The locomotive docks the transporter and pushes the transfer deck portion of the transporter completely inside the emplacement drift transfer dock.
18. The rigid chain mechanism pushes the waste package from inside the shielded transporter enclosure to the transfer deck portion of the transporter.
19. The emplacement gantry, which operates on the emplacement drift rails and is also remotely operated, moves over the waste package, straddling the transporter's transfer deck. (Note: The gantry is placed in the emplacement drift prior to the start of emplacement operations in a particular drift).
20. The emplacement gantry engages the four support points of the emplacement pallet and raises the waste package a few inches above the transporter bedplate.

21. The emplacement gantry is remotely controlled and guided into the emplacement drift to the emplacement location for the particular waste package.
22. The emplacement gantry lowers the waste package to the drift floor and disengages from the four support points of the emplacement pallet.
23. The emplacement gantry is moved back to the emplacement drift entrance for the next emplacement operation.
24. The remote mechanism on the subsurface transporter retracts the bedplate back into the transporter's shielded enclosure.
25. The locomotive moves the transporter away from the emplacement drift docking area and stops. The shielded transporter enclosure doors are closed.
26. The ventilation isolation doors are opened to allow the waste package transporter to pass.
27. The locomotive moves the transporter from the turnout to the main drift and stops to allow the second locomotive to couple to the train.
28. The ventilation isolation doors are closed after the waste package transporter passes.
29. The operators reboard the locomotives; the controls are turned back to manual operation.
30. The secondary locomotive is recoupled to the waste package transporter.
31. The train proceeds to the surface for another emplacement operation.

The sequence for retrieval operations is essentially the reverse of the sequence for emplacement operations.

[Steps 1 through 5](#) are surface operations that either involve no waste package or are conducted remotely with no operator in the vicinity of the transporter. [Steps 6 through 12](#) are conducted manually by operators exposed to the radiation field of the shielded transporter on the way from surface to subsurface locations. During [Step 9](#), operators are exposed to a varying radiation field that peaks as the transporter passes each emplacement drift turnout along the route. As indicated above, [Steps 13 through 28](#) are conducted remotely, with the operators moving to a designated subsurface location near the emplacement drift where the dose rates will be negligible compared to the dose rates to the workers at other steps. In [Steps 29 through 31](#), operators are once again exposed to a varying radiation field until the transporter leaves the emplacement area on its way to the surface.

This input is used to derive the number of emplacement and retrieval workers ([Assumption 4.2.1](#)), and the duration of each step ([Assumption 4.2.2](#)) in which the workers may be exposed to a radiation field.

4.1.2 Width – Emplacement Drift Turnout

The width of an emplacement drift turnout is 8 m wide (BSC 2003a, Table 8).

This input is used in [Assumption 4.2.5](#) to establish the dose-rate profile in the vicinity of turnout locations in Panels 1 through 4.

4.1.3 Layout – Emplacement Drifts in Panels 1 through 4

[Table 1](#) summarizes the number of emplacement drifts within each of the four waste emplacement panels. The table lists the number of emplacement drifts located on the west and/or east side of the waste package transporter route through each panel (BSC 2003a, Figures 6 through 9).

Table 1. Number of Emplacement Drifts in Panels 1 through 4^a

Emplacement Panel [A]	Emplacement Drifts	
	West [B]	East [C]
1	8	0
2	27	0
3	22	19
4	0	30
Total Number of Drifts: 96		

^aSource: BSC 2003a, Figures 6 through 9

A detailed description of each emplacement panel, including projected development and drift turnover sequences, can be found in BSC 2003a (Section 8.4). The detailed description is summarized in the following paragraphs.

The panel numbers correspond to the order in which panel construction and waste emplacement will be conducted. The route to the emplacement drifts in Panel 2 requires that the transporter goes past turnouts number 3 through 8 in Panel 1, which would already contain waste packages. Therefore, 33 turnouts are passed by the transporter en route to emplacement drift number 27 in Panel 2. All transporters destined for Panel 3 will require a reversal in the direction just past turnout number 3 in Panel 1 in order to head north towards Panel 3. In fact, the transporter will likely go past turnout number 3 two times (first southbound, then northbound) en route to Panel 3. Therefore, a transporter destined for west emplacement drift number 1 in Panel 3 will have to travel past 26 turnouts on the west side of the route and 19 turnouts on the east side of the route, for a total of 45 turnouts. Panel 4 may be developed from either the north or south side. The shortest travel distance to Panel 4 is a route between Panels 1 and 2, with emplacement progressing from south to north. The transporter would have to travel a significantly longer distance to reach Panel 4 if emplacement occurred from north to south, since the transporter would have to travel the entire length of Panel 3 to reach Panel 4.

This input is used to determine the number of emplacement drifts passed by a worker crew ([Assumption 4.2.6](#)) and the route that would result in passing the largest number of emplacement drifts to or from the emplacement location ([Section 4.1.4](#) and [Assumption 4.2.7](#)).

4.1.4 Distance – West Turnout Number 1 in Panel 3 to Turnout Number 3 in Panel 1

The distance between west turnout number 1 in Panel 3 and turnout number 3 in Panel 1 covers the transporter route specified in [Section 4.1.3](#) that passes the greatest number of turnouts, assuming Panel 4 is developed from south to north ([Assumption 4.2.6](#)). This distance can be calculated by adding the length of each branch, delimited by nodes along this route. These nodes and branch lengths are obtained from the *Ventilation Network Model Calculation* (BSC 2003c, Attachment A, pp. [D-7](#) to [D-8](#)), and the specific input values applicable to this calculation are reported in [Table 2](#). Note that the branches are numbered in ascending order starting with west turnout number 1 in Panel 3 (Node 3010) and ending with turnout number 3 in Panel 1 (Node 1030).

The total length of all these branches is 6,442 ft. Note that the spacing reported in [Table 2](#) between emplacement drifts located along one side of the route ranges from 268 to 269 ft (e.g., Branch 396 between Node 3010 and Node 3020 is 269 ft long). This is consistent (and slightly conservative) with the 266-ft minimum emplacement drift spacing (center-to-center) criterion (Minwalla 2003, [Section 4.11.2.5](#), p. 234). Multiplying 266 ft by the 24 west-side drift intervals between Panel 1, Drift 3, and Panel 3, West Drift 1 results in a total distance of 6,384 ft, just one percent less than the input value used in this calculation. This input is used in [Assumption 4.2.7](#) to calculate the travel distance through the emplacement area.

Table 2. Distance between West Turnout Number 1 in Panel 3 and Turnout Number 3 in Panel 1^a

Branch Number [A]	Start Node [B]	End Node [C]	Length (ft) [D]	Branch Number [E]	Start Node [F]	End Node [G]	Length (ft) [H]	Branch Number [I]	Start Node [J]	End Node [K]	Length (ft) [L]
396	3010	3020	269	412	3100	3075	199	428	3145	3180	69
397	3020	3030	269	413	3075	3110	69	429	3180	3155	199
398	3030	3040	269	414	3110	3085	199	430	3155	3190	69
399	3040	3015	199	415	3085	3120	69	431	3190	3165	199
400	3015	3050	70	416	3120	3095	199	432	3165	3200	69
401	3050	3025	199	417	3095	3130	69	433	3200	3175	199
402	3025	3060	70	418	3130	3105	199	434	3175	3210	69
403	3060	3035	90	419	3105	3140	69	435	3210	3185	199
404	3035	7214	90	420	3140	3115	199	436	3185	3220	69
405	7214	3070	90	421	3115	3150	69	437	3220	3195	199
406	3070	3045	199	422	3150	3125	199	438	3195	1010	69
407	3045	3080	69	423	3125	3160	69	439	1010	1020	269
408	3080	3055	199	424	3160	3135	199	440	1020	6112	99
409	3055	3090	69	425	3135	3170	90	441	6112	1030	169
410	3090	3065	199	426	3170	7113	90	Total Length = 6,442 ft^b			
411	3065	3100	69	427	7113	3145	90				

^aSource: BSC 2003c, Attachment A, pp. [D-7](#) to [D-8](#)

^bCalculated by summing the lengths of all branches (reported in Columns [D], [H], and [L] of this table).

4.1.5 Distance – North Portal Entrance to Turnout Number 3 in Panel 1

As in [Section 4.1.4](#), this distance can be calculated by adding the length of four branches (Branch 466, 500, 501, and 441), which are delimited by five nodes (Nodes 6110, 6111, 6116, 6112, and 1030) along this route. The branch lengths are obtained from the *Ventilation Network Model Calculation* (BSC 2003c, Attachment A, pp. [D-8](#) to [D-9](#)) and are 6,547, 2,400, 200, and 169 ft, respectively.

The total length of all these branches is 9,316 ft. This input is used in [Assumption 4.2.8](#) to calculate the travel distance between the surface facilities and emplacement area.

4.1.6 External Dose-Rate Criteria – Access Main and Ventilation Door of Emplacement Drift Turnout

In its design options and recommendations, the *Dose Rate Calculation for Emplacement Drift Turnout Configurations* (BSC 2003d, Section 6.4) indicated that “the current dose rate criteria of 1 mrem/hr in the access main and 10 mrem/hr at the ventilation door ... may be overly restrictive for the License Application.” It based this conclusion “in view of substantially automated emplacement operations, and greatly reduced radiation level for the section of the access main shielded by the massive amount of rock.”

“Pending the outcome of an ALARA evaluation,” the report indicated that “it would be desirable to change the dose rate criterion from 1 mrem/hr to 2.5 mrem/hr. Modification to the criterion of 10 mrem/hr at the ventilation door is not recommended, as maintenance on the ventilation door requires periodic human access for hands-on activities.”

Therefore, this calculation uses 2.5 mrem/hr, rather than 1 mrem/hr, as the dose-rate criterion in the access main at the entrance to an emplacement drift turnout. This calculation retains the 10 mrem/hr dose-rate criterion for locations immediately outside the ventilation doors.

This input is used in Assumptions [4.2.5](#) and [4.2.13](#) to derive the dose rates to workers located in the vicinity of emplacement drift turnouts.

4.1.7 External Dose Rate – 10 Meters from Loaded Waste Package Transporter

The external dose rate is 3.71 mrem/hr at a distance of 10 meters from the surface of a loaded waste package transporter when a waste package containing design basis fuel is inside the shielded enclosure. This value is taken from the *Waste Package Transporter Shielding Design Calculation* (BSC 2004, Table 6.3-1).

This input is used in [Assumption 4.2.3](#) to estimate the dose rate to workers involved in coupling a locomotive to a loaded waste package transporter.

4.1.8 Maximum Speed – Waste Package Transporter and Support Equipment

Per the description of the Main Drift Grade in the *Emplacement and Retrieval System Description Document* (BSC 2003b, [Section 3.1.3.1.2](#)), vehicles operating in the main drift shall

not exceed a “maximum normal operating speed of 5 mph for the waste package transporter and 8 mph for support equipment.”

This input is used to derive the speed of the waste package transporter ([Assumption 4.2.9](#)) and maintenance support vehicle ([Assumption 4.2.10](#)).

4.2 ASSUMPTIONS

The following assumptions are used to calculate worker doses.

4.2.1 Number of Workers – Emplacement and Retrieval Operations

The estimated number of workers is based on engineering judgment and follows the sequence of operations described in [Section 4.1.1](#). [Table 3](#) lists the number of workers required to perform each step in which workers are exposed to radiation during emplacement and retrieval operations.

Table 3. Number of Workers Required to Perform Emplacement and Retrieval Steps

Step Number (Section 4.1.1) [A]	Number of Workers [B]	Rationale [C]
1, 2, 3	N/A – No or Low Radiation Field	These steps are conducted in a zero or very low radiation field; workers receive a negligible dose from these steps.
4, 5, 6a	N/A – Remote; Operators in Low Radiation Field	These steps are conducted remotely in radiation fields; no workers are present in the vicinity of the operations and receive zero doses from these steps.
6b	2	This step involves operating a primary locomotive with a two-person crew (W1/W2).
7	4	The two-person crew of the secondary locomotive (W3/W4) performs this step; the crew of the primary locomotive (W1/W2) stays in the cab during this operation. The dose rates to W3/W4 are higher than the dose rates to W1/W2 due to their proximity to the waste package transporter and absence of any cab shielding.
8, 9, 10, 11	4	These steps involve two locomotives, each with a two-person crew (W1/W2/W3/W4).
12	2	The crew of the primary locomotive performs this task (W1/W2). The crew of the secondary locomotive (W3/W4) has moved to standby location as a result of Step 11.
13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	N/A – Remote; Operators in Low Radiation Field	These steps are conducted remotely in radiation fields; no workers are present in the vicinity of these operations. All workers are standing by in a location with very low radiation fields during these steps and receive negligible doses.
29, 30, 31	4	All four locomotive operators (W1/W2/W3/W4) are involved in these steps, conducted without a waste package in the transporter.

N/A: Not applicable

For some steps, workers will not be significantly exposed either because the activity is conducted remotely, or because the activity occurs away from any radiation field. In those cases, the number of workers is listed as N/A because no significant dose is incurred in those steps. In the

worker dose calculations ([Section 6.1.1](#)), the two crew members of the primary locomotive are identified as W1/W2, and the two crew members of the secondary locomotive are identified as W3/W4.

Rationale: The rationale for the number of involved workers is given in the last column of [Table 3](#).

Usage: These assumptions are used in [Section 6.1.1](#).

4.2.2 Exposure Duration – Emplacement and Retrieval Operations

The time spent by workers in the radiation fields for each of the steps in [Section 4.1.1](#) is based on engineering judgment or is calculated in [Section 6.1.1](#). These times are listed in [Table 4](#) for each step. As was the case for [Assumption 4.2.1](#), in some steps workers will receive a negligible dose because the activity is conducted remotely, or because the activity occurs in very low radiation fields. In those cases, the exposure duration is listed as N/A because no significant worker doses are incurred in those steps.

Rationale: The rationale for the amount of time spent in the radiation field is given in the last column of [Table 4](#). These times are difficult to quantify accurately in the absence of actual operational data. However, the times chosen are considered to be overestimates, resulting in a conservative dose calculation.

Usage: These assumptions are used in [Section 6.1.1](#).

4.2.3 Dose Rate – At Coupling Location (Loaded Waste Package Transporter)

The operators that manually couple the secondary locomotive to a loaded waste package transporter are assumed to perform this operation at a distance of 10 m from the nearest surface of the shielded enclosure. At this distance, the calculated dose rate from a shielded design basis waste package is 3.71 mrem/hr (see [Section 4.1.7](#)).

Rationale: Ten meters is a conservative distance based on the transporter dimensions and secondary locomotive coupling location shown in [Figure 2](#).

End-to-end transporter dimensions are 78 ft 11.25 in. (24 m), and the length of the shielded enclosure is 21 ft 11 in. (6.7 m). The primary locomotive coupling location is approximately five meters from the nearest surface of the shielded enclosure. However, the only coupling operation performed by operators when a waste package is present inside the shielded enclosure involves the secondary locomotive ([Section 4.1.1](#)).

The use of the dose rate for a design basis waste package is conservative. As indicated in [Assumption 4.2.15](#), the dose rates from an average waste package inside the shielded enclosure would be at least a factor of five times lower.

Usage: This assumption is used in [Section 6.1.1](#) to calculate the dose to workers performing the coupling operations when a dose package is present inside the waste package transporter ([Step 7](#) in [Section 4.1.1](#)).

Table 4. Time Spent by Workers to Perform Emplacement and Retrieval Steps

Step Number (Section 4.1.1) [A]	Time in Radiation Field (hr) [B]	Rationale [C]
1, 2, 3	N/A – No or Low Radiation Field	These steps are conducted in a zero or very low radiation field. Therefore, the time to conduct these operations is not relevant or needed for the purpose of this design calculation.
4, 5, 6a	N/A – Remote; Operators in Low Radiation Field	These steps are conducted remotely in relatively high radiation fields; no workers are present in the vicinity of these operations or radiation fields. In addition, it is assumed that any dose-rate monitoring of the waste package transporter radiation field will be conducted remotely (e.g., using portal monitors). Therefore, the time to conduct these steps is not needed for the purpose of this design calculation.
6b	0.1	This step is estimated to take no longer than 1/10 th of an hour (6 minutes), the smallest increment of time considered in this calculation due to the uncertainties in the time estimates. This assumption is based on engineering judgment.
7	0.5	This step is estimated to take half an hour based on engineering judgment.
8	0.1	This step is estimated to take no longer than 1/10 th of an hour based on engineering judgment.
9	Variable – Calculated in Section 6.1.1	The total time for this step is the sum of the travel time from the surface turnouts to the North Portal, travel time from the North Portal to an emplacement panel, and travel time through the emplacement panel to the emplacement drift. Each segment is calculated separately in Section 6.1.1 because the radiation fields vary along the route.
10	≅0 (included in Step 9)	The train's stoppage distance (and time) from full speed has not been determined, but is estimated to be considerably less than 1/10 th of an hour. The two locomotive crews begin their exposure to the radiation field in the emplacement drift turnout area, but this initial time is factored into the travel time calculation for Step 9 by including the destination emplacement drift in the number of drifts passed by the transporter en route to its destination.
11	0.5	Time is based on the assumption that the same amount of time is needed to uncouple and maneuver the second locomotive to the standby location as is needed to couple the locomotive in Step 7. However, in this case, the uncoupling is performed remotely while the two locomotive crews stay in their cabs. In addition, the uncoupling operation is assumed to occur outside the radiation field of the turnout.
12	≅0 (negligible duration)	Turning over control to the remote operator, and the operators moving to the standby location, is assumed to take less than one minute.
13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	N/A – Remote; Operators in Low Radiation Field	These steps are conducted remotely in radiation fields; no workers are present in the vicinity of these operations or radiation fields. All workers are standing by in a very low radiation field during these steps and receive a negligible dose. Therefore, the time to conduct these operations is not relevant or needed for the purpose of this design calculation.
29	0.1	Switching both locomotives back to manual mode is estimated to take less than 1/10 th of an hour. This step includes the time it takes for the crew of the second locomotive to approach the waste package transporter prior to coupling.
30	N/A – Negligible Radiation Field	Coupling the second locomotive is assumed to occur at a standby location that is far enough removed from the turnout entrance, a location where the dose rates are negligible.
31	Variable – Calculated in Section 6.1.1	The total time for this step is the sum of the travel time from the emplacement drift through the emplacement panel, travel time from an emplacement panel to the North Portal, and travel time from the North Portal to the surface facility. Each segment is calculated separately in Section 6.1.1 because the radiation fields vary along the route.

N/A: Not applicable

4.2.4 Dose Rate – Inside Locomotive Cab

The locomotive cabs are assumed to be shielded, if necessary, so that the dose rate to operators inside the cabs will not exceed 2.5 mrem/hr when the locomotive is coupled to a transporter containing a waste package inside the shielded enclosure.

Rationale: The *Project Design Criteria Document* (Minwalla 2003, [Table 4.9.1-1](#)) lists as one of its criteria the requirement that the individual annual TEDE not exceed 5,000 mrem, consistent with the requirements in Section 4.3 of this calculation. While operators will not be in the locomotive cab continuously, they would spend a good portion of the emplacement or retrieval operation inside the cab. A dose-rate limit of 2.5 mrem/hr inside the cab ensures that even if the operators were to spend a full work year inside the cab (2,000 hrs per work year), their exposure would not exceed 5,000 mrem from design basis waste packages.

The use of this dose-rate criterion (for a design basis waste package) is conservative. As indicated in [Assumption 4.2.15](#), the dose rates inside the transporter cab from an average waste package inside the shielded enclosure would be at least a factor of five times lower.

The dimensions of the locomotive and waste package transporter are provided in [Figure 2](#). The distance between the rear wall of the cab and rear hitch, to which the waste package transporter would be attached, is approximately 9 m. The distance to the nearest surface of the waste package transporter's shielded enclosure is approximately 14 m (9 m + 5 m, see [Assumption 4.2.3](#)). Since the secondary locomotive is dimensionally identical to the primary locomotive, this assumption is even more conservative since the second locomotive's cab would be at a greater distance (approximately 21 m) from the nearest surface of the shielded enclosure.

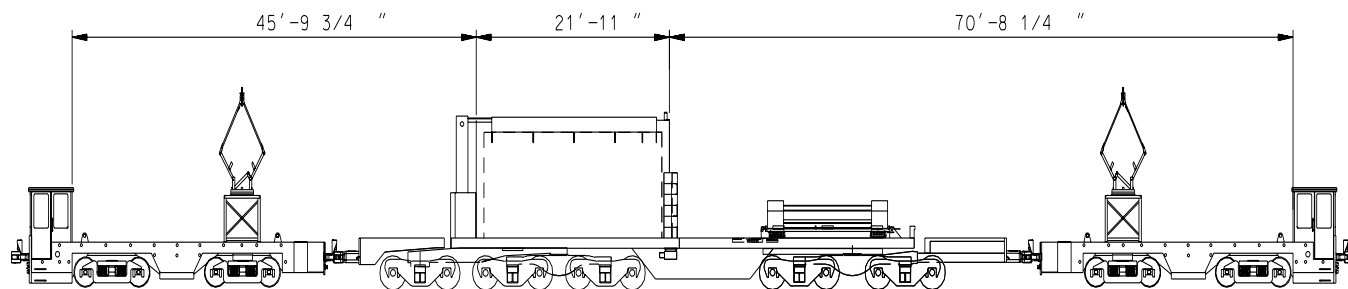


Figure 2. Waste Package Transporter and Two Locomotives

Usage: This assumption is used in Sections [3.1](#) and [6.1.1](#) to calculate the dose to workers inside the locomotive cabs while a transporter containing a waste package is coupled to one or both locomotives ([Steps 6 through 12](#) described in [Section 4.1.1](#)).

4.2.5 Dose Rate - Vicinity of Turnout Locations

The dose rates at the turnout locations along the main access routes are assumed to be equal to the 2.5 mrem/hr dose-rate criterion over the entire 8-m width of the turnout opening (per Sections [4.1.6](#) and [4.1.2](#), respectively). The dose rate is assumed to linearly drop to negligible levels along the access main within 8 m on either side of the turnout opening, resulting in an

effective opening that is 24 m wide. This dose-rate profile is illustrated graphically in [Figure 3](#), with points labeled in a similar manner as in [Figure 1](#).

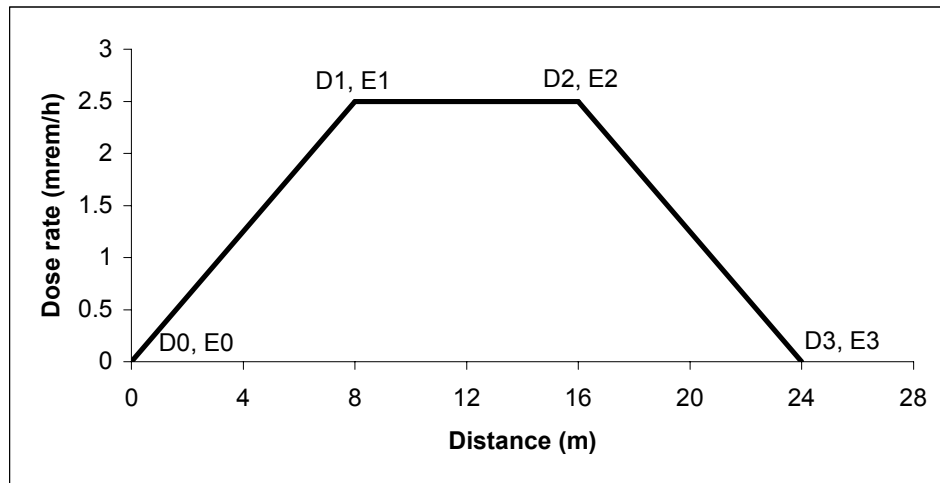


Figure 3. Assumed Dose-Rate Profile in the Vicinity of an Emplacement Drift Turnout

Rationale: This simplifying and conservative assumption is appropriate to estimate average dose rates along the waste package transporter route. The access main dose-rate criterion ([Section 4.1.6](#)) is driven by dose calculations using design basis waste packages placed near an emplacement drift entrance. No direct radiation reaches the workers outside the emplacement drift, and the entire dose is contributed by scattered radiation. Moving along the transporter route away from this centrally located dose point, the dose rate drops to a negligible level as the repository rock matrix shields most of the scattered radiation originating from waste packages inside the emplacement drift. This is supported by the conclusion in [Section 4.1.6](#), “in view of ... (the) greatly reduced radiation level for the section of the access main shielded by the massive amount of rock.”

In addition, the average dose rates at the turnout locations are expected to be significantly lower due to the bounding considerations inherent in using design basis waste packages to derive the access main dose-rate criteria. Finally, any shielding used in the locomotive cab to reduce the exposure to workers from a loaded waste package transporter should also be effective at reducing the radiation field around the turnout locations. In this calculation, no credit is taken for any cab shielding that would reduce the radiation field in the vicinity of emplacement drift turnouts.

Usage: This assumption is used in [Sections 3.1](#) and [6.1.1](#), along with [Equations 4](#) and [5](#), to calculate mean dose rates to workers (including maintenance workers) traveling along the transporter route. It is also used in estimating doses from operations that take place in the vicinity of an emplacement drift turnout ([Steps 9 through 12](#) and [Steps 29 through 31](#) described in [Section 4.1.1](#)), as well as maintenance operations in these areas.

4.2.6 Maximum Number of Emplacement Drift Turnouts Passed by Vehicle – Emplacement/Retrieval and Maintenance Operations

The emplacement route that would result in the highest dose to either emplacement/retrieval or maintenance workers in any year of operation is assumed to be between West Turnout Number 1 in Panel 3 and Turnout Number 3 in Panel 1, since this route involves passing 45 emplacement drifts.

Rationale: This assumption is based on the layout of the emplacement drifts summarized in [Section 4.1.3](#). A route maximizing the number of turnouts passed by the waste package transporter (or maintenance crew support vehicle) and the amount of time it takes the vehicles to reach their destination is assumed to maximize the dose to workers. A north-to-south route through Panel 4 may result in higher annual doses to workers since this routing would require traversing all of Panel 3. However, a south-to-north emplacement route in Panel 4 is considered more likely as it would reduce the distance the transporter would have to travel to reach the average emplacement drift in Panel 4. While the length of Panel 4 is greater than the length of Panel 3, only 30 turnouts are located in Panel 4 compared to the 45 turnouts passed by a transporter en route to the last emplacement drift in Panel 3. In addition, the route to Panel 3 requires the transporter to reverse directions in the Panel 1 area. The time needed to perform this operation may offset some of the additional travel time spent by a transporter en route to the final emplacement drift in Panel 4.

Usage: This assumption is used in [Sections 6.1.1](#) and [6.2.1](#), along with [Equation 4](#), to calculate average dose rates along this route.

4.2.7 Travel Distance – Through Emplacement Area

The dose-maximizing distance through an emplacement area in any year is assumed to be between west turnout number 1 in Panel 3 and turnout number 3 in Panel 1. This distance is 1,964 m.

Rationale: The total travel length was reported as 6,442 ft in [Section 4.1.4](#) and converted to meters (0.3048 m/ft). This assumption represents an overestimate since it does not take credit for more than one emplacement drift filled per year ([Assumption 4.2.11](#)). Therefore, the average travel distances through Panel 3 will always be less than this estimate since only the last emplacement drift in Panel 3 is located at this dose-maximizing travel distance.

Usage: This assumption is used in [Section 6.1.1](#), along with Equations [4](#) and [6](#), to calculate average dose rates and travel times along this dose-maximizing route.

4.2.8 Travel Distance – Between Surface Facilities and Emplacement Area

The distance traveled by the waste package transporter between the surface facilities and emplacement area is assumed to be 3,540 m.

Rationale: The layout of the surface facilities, including the total length of the tracks between surface and subsurface facilities, has not been finalized. Therefore, this value is based on a conservatively estimated distance of 700 m between the surface facilities and North Portal, plus

2,840 m between the North Portal and turnout number 3 in Panel 1. The first segment (surface facilities to North Portal) is based on an approximate rail length of 2,000 ft between DTF-2 and the North Portal shown on the *Geological Repository Operations Area North Portal – Site Plan* (BSC 2003e), plus a 10 percent contingency, converted to meters (0.3048 m/ft). Other surface facilities (DTF-1 and CHF) will likely involve shorter rail distances to the North Portal. The second segment (North Portal to emplacement area) was reported as 9,316 ft in [Section 4.1.5](#) and converted to meters (0.3048 m/ft).

Usage: This assumption is used in [Section 6.1.1](#), along with [Equation 7](#), to calculate travel times along the transporter route.

4.2.9 Travel Speed – Waste Package Transporter

The waste package transporter is assumed to travel at an average speed of 4 mph.

Rationale: As indicated in [Section 4.1.8](#), the maximum normal operating speed of the waste package transporter is 5 mph. Travel times (and exposure duration) are minimized when the waste package transporter travels at this maximum speed. However, it is not conservative or realistic to assume that the fully loaded transporter will be able to sustain this speed over the entire route, since some routes require the transporter to stop and reverse directions. Therefore, a conservative assumption is made that the average transporter speed is 4 mph. Operating the transporter at slower speeds would increase the travel time and worker exposures, but there are operational incentives to run the transporter at the highest possible safe speed. Therefore, a value that is 20 percent below the maximum allowable transporter speed is considered to be realistic for purposes of this calculation.

Usage: This assumption is used in Sections [3.1](#), [6.1.1](#), and [6.2.1](#), along with Equations [6](#) and [7](#), to calculate travel times along the transporter route.

4.2.10 Travel Speed – Support Equipment

The travel speed for support equipment is assumed to be 8 mph.

Rationale: The maximum allowable speed for support equipment specified in [Section 4.1.8](#) provides a realistic estimate for the calculation of doses to maintenance workers when in transit to the work locations. While slower speeds would result in more conservative dose estimates, there are operational incentives to run the support vehicle at the highest allowable safe speed. In addition, the dose contribution from transit through the emplacement panels is much smaller than the doses incurred during the actual maintenance operations (see [Section 6.2.1](#)). Therefore, the total doses are not very sensitive to the value of this parameter.

Usage: This assumption is used in Sections [3.1](#) and [6.2.1](#), along with [Equation 6](#), to calculate travel times through an emplacement panel.

4.2.11 Number of Crews/Waste Packages – Emplacement and Retrieval Operations

The number of waste packages emplaced each year is assumed to be less than or equal to 600. A minimum of two work shifts would be required to accommodate this throughput. It is, therefore,

assumed that each crew will transport an average of 300 waste packages annually to or from the emplacement drifts during years in which this maximum assumed throughput is effective. At this emplacement rate, five drifts would be subject to emplacement operations in one year.

Rationale: The peak emplacement rate assumption of 600 waste packages per year is consistent with the assumption contained in the *Recommended Surface Contamination Levels for Waste Packages Prior to Placement in the Repository* (Edwards and Yuan 2003, [Section 4.2.2](#)) and is conservative compared to Cloud 2003 ([Table 4](#)). It represents an upper bound estimate of the annual waste-package emplacement rate.

The number of active drifts in one year, at a rate of 600 waste packages emplaced per year, is based on:

- Average emplacement drift length of 692 m, based on 66,450 m total drift length (BSC 2003a, Table 8) and 96 drifts ([Table 1](#))
- Design basis waste package length of 202.7 in. (5.25 m) (BSC 2003b, Table 3)
- Average spacing (skirt-to-skirt) of 4 in. (0.10 m) between waste packages (BSC 2003b, Section 3.1.2.2.3).

This results in 132 waste packages per average drift, or an average of 4.6 drifts (rounded up to 5 for conservatism) per year in which 600 waste packages are emplaced.

It is assumed to take between four and eight hours to emplace or retrieve a single waste package. In order to handle two waste packages in a day, at least two emplacement and retrieval crews (and possibly a partial third crew, if the first two crews are limited to a 250-day work year with no overtime) would be needed. For conservatism in calculating individual doses, only two crews are assumed to be required for this operation.

Usage: This assumption is used in [Section 6.1](#), along with Equations [1](#) and [3](#), to calculate individual and collective doses to emplacement and retrieval workers.

4.2.12 Crew Size, Duration, and Frequencies – Maintenance Operations

A list of operational steps has not been formally developed for each of the subsurface maintenance operations. Therefore, the sequence of operations for such activities is listed here as a series of assumptions based on engineering judgment. [Table 5](#) summarizes the crew-size assumptions and the estimated duration and frequencies of ventilation, electrical, mechanical (rail), and ground control maintenance operations.

These operations are further broken down into component steps in the discussion of the rationale for each operation. The first worker in each crew is identified as W1 and, where applicable, the second and third workers in a crew are identified as W2 and W3, respectively.

Table 5. Duration, Crew Size, and Frequency for Various Maintenance Operations

Maintenance Operation [A]	Crew Size [B]	Duration (hrs) [C]	Operations per Year [D]
Ventilation	3	3.2	10
Electrical	1	3.5	12
Mechanical	3	8	5
Ground Control	1	8	2

Rationale (Ventilation System Maintenance): There is no planned maintenance for the door actuator. The actuator will only be needed to operate a few hundred times during emplacement (based on approximately 132 waste packages per drift [see [Assumption 4.2.11](#)]). The actuator will be remotely tested to see if it is operational and, if found to be inoperable, it can be replaced (when access is required) using similar procedures to maintenance in the turnout (e.g., using temporary shielding). The failure rate on the actuator is expected to be very low.

The only planned maintenance will be on the louver, which is a bolt-on item. It is estimated that maintenance will be required every 10 years. With 96 full drifts (see [Table 1](#)), this corresponds to approximately 10 maintenance operations per year.

The ventilation crew is estimated at three workers:

- One worker to disconnect, calibrate, and reconnect controls (W1)
- Two workers to remove and install louvers (W2, W3).

A detailed breakdown of the estimated work process for ventilation system maintenance is:

- 0.25 hr to mobilize and set up (W1, W2, W3)
- 0.50 hr to disconnect controls (W1)
- 0.50 hr to unbolt and remove louver (W2, W3)
- 0.50 hr to reinstall the louver (W2, W3)
- 0.50 hr to reconnect and calibrate controls (W1)
- 0.25 hr to demobilize (W1, W2, W3).

Total time: 2.5 hrs plus 1/3 contingency for level of the estimate, or 3.2 hrs (approximately half a shift per operation). Therefore, the total time per year spent on ventilation system maintenance would be 32 hrs per worker, or 96 total staff-hrs, excluding travel time to the work location. When only one or two workers are performing a given task, the other(s) is assumed move to the access main where the dose rate is lower. Therefore, all three workers spend a total of 1.5 hrs, plus contingency (or 2 hrs), at the door. The balance of the time is spent in the access main.

Rationale (Electrical System Maintenance): There will be no required scheduled maintenance on the transformers that would increase the worker dose because of where they are located. The motor on the door will require maintenance while emplacement is ongoing. With minimal access required after emplacement, there will be no scheduled maintenance after emplacement is completed. The motor will be tested remotely, similar to the actuator, and follow similar procedures. While emplacement is ongoing, it is estimated that each motor will require maintenance each month. The emplacement rate is approximately five drifts per year ([Assumption 4.2.11](#)). Based on the expected thermal loading of the drifts, it is conservatively

estimated that seven drifts could require maintenance during any given month (allowing for two spare drifts). Although all the work would be conducted at the door, it should be noted that dose rates are based on loaded drifts, so the majority of the maintenance work being performed would actually be under substantially lower dose rates from partially filled drifts.

A detailed breakdown of the estimated work process is:

- 0.25 hr to inspect connections (W1)
- 0.25 hr to inspect and maintain lubrication (W1).

Total time: 0.5 hr per drift. Assuming seven drifts are inspected each month results in a total of 3.5 hrs per inspection-month. Therefore, the total work would be 42 hrs per year (42 total staff-hrs), excluding travel time to the work location.

Rationale (Mechanical System Maintenance): Rail maintenance will not be required. However, after emplacement is complete, the switches to the emplacement drifts will be removed to reduce the potential of derailments and to minimize maintenance. The switch area will be made of concrete to expedite the change over. By using concrete in the intersection, the potential for derailments of the transporter and time spent in the area is reduced, which would substantially reduce the overall worker dose. Approximately five drifts will be filled per year, so five switches would be removed each year.

The rail (mechanical) crew is estimated at 3 workers:

- One equipment operator (W1)
- Two workers to remove and install rails (W2, W3).

A detailed breakdown of the estimated work process is:

- 0.25 hr to mobilize and set up
- 1.00 hr to unbolt switch
- 2.00 hrs to remove frog and switch assemble (with a forklift)
- 1.00 hr to remove old rail and move new section into work area
- 1.00 hr to cut and drill hole to fit new section of rail into place
- 0.50 hr to install new rail
- 0.25 hr to demobilize.

Total time: 6 hrs plus 1/3 contingency for level of the estimate, or 8 hrs (one shift per operation). Therefore, the total time spent on mechanical (rail) maintenance would be 40 hrs per worker, or 120 total staff-hrs, excluding travel time to the work location. All maintenance operations would be conducted in the access main in the vicinity of the turnouts; therefore, all three workers are subject to the same dose rates.

Note that the estimate for changing out a switch from a ballast roadbed is two to three shifts, versus one shift for changing out a switch from a concrete roadbed.

Rationale (Ground Control System Maintenance): Ground control will be installed to minimize maintenance; therefore, there is no planned ground control maintenance. Any maintenance that

may occur can be handled similarly to the unplanned work in the turnout using, for example, temporary shielding. The only exposure to the ground control crew would be when conducting planned inspections. In areas that are inaccessible to humans (e.g., turnouts, emplacement drift, and exhaust main), inspections will be done remotely. Inspections in the intake mains can be done manually. The intersections will be monitored using extensimeters, so the frequency of manual inspections can be reduced. It is estimated that each intersection will be inspected twice per year by one person. There are 96 drifts (see [Table 1](#)) to be inspected, which will be done from the rail as the inspector slowly travels through the mains.

It is estimated to take five minutes to inspect each of 96 intersections.

Total time: 8 hrs per inspection. Therefore, the total work would be 16 hrs per year (16 total staff-hrs), which includes travel time.

Usage (applies to all maintenance/inspection operations): These assumptions are used in Sections [3.2](#), [6.2.1](#), and [6.2.2](#), along with Equations [2](#) and [3](#), to calculate individual and collective doses to maintenance workers.

4.2.13 Dose Rates – Maintenance Operations

The assumed dose rates at each maintenance location are listed in [Table 6](#), along with the rationale for these assumptions.

Table 6. Dose Rates at Various Maintenance Operations Locations

Maintenance Location [A]	Dose Rate (mrem/hr) [B]	Maintenance System [C]	Rationale [D]
Intersection of Turnouts and Access Main	2.5	Ventilation Mechanical Ground Support	Per Section 4.1.6 and Assumption 4.2.5 of this calculation. Applies to ventilation system personnel standing by while others are performing work at the emplacement drift door.
Emplacement Drift Vent Door	10	Ventilation Electrical	Per criteria in Section 4.1.6 . Applies to ventilation system only for time spent at the emplacement drift door.
Transport Route through Emplacement Panel	Calculated in Section 6.2.1	Ventilation Electrical Mechanical	Calculated using Equation 4 .

Rationale: See last column in [Table 6](#) for the rationale applicable to each maintenance location.

Usage: These assumptions are used in [Section 6.2.1](#), along with [Equation 2](#), to calculate individual doses to maintenance workers.

4.2.14 Interaction between Emplacement/Removal and Maintenance Operations

Operations involving emplacement or retrieval of waste packages are assumed to be conducted at different times from operations involving subsurface facility maintenance.

Rationale: Maintenance operations occur at a relatively low frequency ([Assumption 4.2.12](#)). The emplacement and retrieval operations, while performed more frequently

([Assumption 4.2.11](#)), allow maintenance crews to enter the repository to conduct operations at times and/or locations when or where no waste packages are in the process of being emplaced or retrieved. Therefore, it is reasonable to assume that any radiation fields due to emplacement and retrieval operations (e.g., from a waste package inside a shielded transporter en route to an emplacement drift) will not add to the doses calculated for maintenance workers.

Usage: This assumption is used throughout [Section 6](#) to calculate individual doses to all subsurface workers.

4.2.15 Dose-Rate Reduction Factor – Design Basis Waste Package to Average Waste Package

The average dose-rate reduction factor between the design basis waste package and average waste package is assumed to be five.

Rationale: The basis for this scaling factor is provided in [Attachment I](#) to this calculation. The exposure geometry between workers and waste packages (either on the transporter or in an emplacement drift) is primarily along the waste package axial direction. That is, the workers are exposed primarily by radiation leaving the tops or bottoms of waste packages (axial direction), rather than radiation emitted from the sides (radial direction). All the calculated scaling factors for the axial geometry discussed in Attachment I ([Table I-1](#)) range from 5.52 to 6.74. Therefore, an average factor of five applied to all conditions is conservative.

Usage: This assumption is used throughout [Section 6](#) to calculate average annual individual and collective doses to all subsurface workers.

4.3 REGULATIONS

The regulation applicable to worker doses is contained in 10 CFR 20.1201, *Occupational Dose Limits for Adults*:

- (a) The licensee shall control the occupational dose to individual adults to the following dose limits:
 - (1) An annual limit, which is the more limiting of:
 - (i) The total effective dose equivalent being equal to 5 rems;
 - or
 - (ii) The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems.
 - (2) The annual limits to the lens of the eye, to the skin, and to the extremities, which are:
 - (i) A lens dose equivalent of 15 rems, and
 - (ii) A shallow-dose equivalent of 50 rems to the skin or to any extremity.

4.4 CRITERIA

As low as is reasonably achievable (ALARA) design goals (Minwalla 2003, [Sections 4.9.3.2 and 4.9.3.3](#)) for occupational workers ensure that both individual and collective annual doses are maintained at ALARA levels during normal operations and as a result of Category 1 event sequences.

The following ALARA design goal is established for the design process:

- The ALARA design goal for individual radiation worker doses is to minimize the number of individuals that have the potential of receiving more than 500 mrem/yr TEDE. That goal is 10 percent of the annual TEDE limit in 10 CFR 20.1201, and includes both internal and external exposures.

5. USE OF SOFTWARE

5.1 BASELINED SOFTWARE

No software subject to verification under AP-SI.1Q, *Software Management*, was used in this design calculation.

5.2 COMMERCIAL OFF-THE-SHELF SOFTWARE

Only commercial off-the-shelf software was used in this calculation.

5.2.1 Microsoft Excel 97 SR-2

- Title: Excel
- Version/Revision Number: Microsoft® Excel 97 SR-2
- This version is installed on a Dell OptiPlex GX270 PC running the Microsoft Windows 2000 operating system (property tag YMP000730).

Microsoft Excel 97, a spreadsheet program, is used in this calculation. Excel was used to generate tables listing the emplacement, maintenance, and retrieval operations; travel distances; number of workers involved in each operation; dose rates at worker locations; and time spent by the workers in the radiation field at each location. Excel was also used to generate the dose-rate profiles shown in Figures 1 and 3. Methodologies and equations (derived in [Section 3](#)), design parameters and assumptions (listed in [Section 4](#)), and calculations (performed in [Section 6](#)) are documented in sufficient detail to allow for independent duplication of the various computations without recourse to the originator or the original spreadsheet. Per [Section 2.1.6](#) of AP-SI.1Q, this software is considered exempt.

6. CALCULATION

Individual and collective worker doses are calculated by applying equations and methodologies described in [Section 3](#) and by using design inputs defined in [Section 4](#). Doses to emplacement and retrieval workers are calculated in [Section 6.1](#), while doses to maintenance workers are calculated in [Section 6.2](#).

Calculated values are presented (rounded) only to the appropriate number of significant digits; however, calculations using Excel are carried out without regard to the number of significant digits in order to reduce round-off error between steps.

6.1 EMPLACEMENT AND RETRIEVAL WORKER DOSES

Annual doses to individual emplacement and retrieval workers are calculated in [Section 6.1.1](#). These doses are then summed in [Section 6.1.2](#) to calculate the collective dose to this group of workers.

6.1.1 Individual Worker Doses – Emplacement or Retrieval Operations

The anticipated sequence of emplacement operations is described in [Section 4.1.1](#). The number of workers ([Assumption 4.2.1](#)) and exposure duration ([Assumption 4.2.2](#)) used in calculating the doses for each operational step are listed in Tables [3](#) and [4](#), respectively. The exposure times for operational Steps [9](#) and [31](#) are calculated as follows.

[Step 9](#) includes travel time from the surface turnouts to the North Portal and from the North Portal to an emplacement panel ([Step 9a](#)). The transporter then travels through the emplacement panel to the emplacement drift ([Step 9b](#)). Because the radiation fields vary along the route, each segment is calculated separately as follows:

- [Step 9a](#): Use [Equation 7](#), $T_{S-SS} = D_{S-SS}/(1610 \times S_T)$, where $D_{S-SS} = 3,540$ m ([Assumption 4.2.8](#)) and $S_T = 4$ mph ([Assumption 4.2.9](#)). $T_{S-SS} = 3540/(1610 \times 4) = 0.55$ hr.
- [Step 9b](#): Use [Equation 6](#), $T_{TO} = D_{ED}/(1610 \times S_T)$, where $D_{ED} = 1,964$ m ([Assumption 4.2.7](#)) and $S_T = 4$ mph ([Assumption 4.2.9](#)). $T_{TO} = 1964/(1610 \times 4) = 0.30$ hr.

On the return trip through the emplacement area ([Step 31a](#)), the same transit time (0.30 hr) would apply. Since any dose rates to workers outside the emplacement area are negligible when the transporter does not contain a waste package, the travel time to return to the surface ([Step 31b](#)) is not required for this calculation.

The dose field to which workers are exposed in [Step 9a](#) is 2.5 mrem/hr ([Assumption 4.2.4](#)) since the locomotive operators are assumed to be inside the cab, and the only contribution to the dose is from the waste package inside the transporter's shielded enclosure. This dose field is still present in [Step 9b](#), but a variable contribution from the scattered radiation in the emplacement drift turnouts is added to this stationary field as the transporter passes each turnout.

The dose rates at the turnout locations along the main access routes are assumed to be equal to the 2.5 mrem/hr dose-rate criterion ([Section 4.1.6](#)) over the entire 8-m width of the turnout opening ([Section 4.1.2](#)). This dose rate is assumed to linearly drop to negligible levels along the access main within 8 m on either side of the turnout opening ([Assumption 4.2.5](#), not including the 2.5 mrem/hr contribution from any waste package being transported). This assumed dose-rate profile is illustrated in [Figure 3](#). The average dose rate over the effective emplacement drift opening is calculated using [Equation 5](#), where:

$$i = 1, 2, 3$$

$$E_{0,1,2,3} = 0, 2.5, 2.5, \text{ and } 0 \text{ mrem/hr, respectively}$$

$$D_{0,1,2,3} = 0, 8, 16, \text{ and } 24 \text{ m, respectively}$$

Note that in this dose-rate profile, all distance increments ($D_i - D_{i-1}$) are equal to 8 m. This value and the factor of 2 in the denominator can be taken out of the summation as a constant multiplicative factor. Therefore, the equation simplifies to $EDR_{TO} = \{[(0 + 2.5) + (2.5 + 2.5) + (2.5 + 0)]/2\} \times (8/24)$, or 1.67 mrem/hr.

Assuming a constant travel speed past each turnout location ([Assumptions 4.2.9](#) and [4.2.10](#)), the dose integration is mathematically equivalent to a constant dose rate of 1.67 mrem/hr over an effective distance of 24 m, and a negligible dose rate outside this distance (until reaching the next turnout area).

This variable field is calculated as an average over the transporter route using [Equation 4](#) as follows:

$$EDR_{Av} = (EDR_{TO} \times N_{ED} \times D_{TO})/D_{ED} + \{EDR_{Main} \times [D_{ED} - (N_{ED} \times D_{TO})]\}/D_{ED}, \text{ where } EDR_{TO} = 1.67 \text{ mrem/hr (Calculated Value), } N_{ED} = 45 \text{ (Assumption 4.2.6), } D_{TO} = 24 \text{ m (Assumption 4.2.5), } EDR_{Main} \cong 0 \text{ mrem/hr (Assumption 4.2.5), and } D_{ED} = 1,964 \text{ m (Assumption 4.2.7). } EDR_{Av} = (1.67 \times 45 \times 24)/1964 + 0 = 0.92 \text{ mrem/hr.}$$

Adding the constant dose rate of 2.5 mrem/hr from the waste package inside the transporter results in an effective dose rate of 3.4 mrem/hr during [Step 9b](#). The same variable fields will be experienced by the crew on the return trip through the emplacement area ([Step 31a](#)), but without the waste package inside the transporter. Therefore, the corresponding effective dose rate for [Step 31a](#) is 0.92 mrem/hr.

The dose to workers transiting through the emplacement panel is simply the product of transit time and average dose rate. Thus, for [Step 9a](#), the dose is 0.55 hr \times 2.5 mrem/hr, or 1.4 mrem; for [Step 9b](#), the dose is 0.30 hr \times 3.4 mrem/hr, or 1.0 mrem; and for [Step 31a](#), the dose is 0.30 hr \times 0.92 mrem/hr, or 0.28 mrem. There would be no additional exposures to workers once they leave the emplacement area on the return trip ([Step 31b](#)).

The dose rates to each crewmember are the same for most emplacement and retrieval steps. One exception to this rule occurs in [Step 7](#) ([Assumption 4.2.1](#)), where two members of the four-person crew are assumed to be exposed to a field of 3.71 mrem/hr ([Assumption 4.2.3](#)), and the other two are exposed to a field of 2.5 mrem/hr ([Assumption 4.2.4](#)). This difference is accounted for in this calculation by dividing [Step 7](#) into [Step 7a](#) (two workers outside the

locomotive cab) and [Step 7b](#) (two workers inside the locomotive cab). In addition, not all four crewmembers will be present for all operational steps, as indicated in [Assumption 4.2.1](#). For example, only the crewmembers of the primary locomotive are involved in Steps [6](#) and [12](#).

Steps [10](#), [12](#), and [29](#) are assumed to be conducted in the radiation field of the emplacement drift entrance (2.5 mrem/hr – [Assumption 4.2.5](#)). In Steps [10](#) and [12](#), the contribution from the loaded waste package transporter is added to this dose rate (2.5 mrem/hr – [Assumption 4.2.4](#)) for a total of 5 mrem/hr during these steps. In [Step 29](#), the waste package transporter is empty and does not contribute to the dose rate, resulting in a dose rate of 2.5 mrem/hr at the turnout location.

Combining the applicable assumptions from [Section 4.2](#) with the exposure duration and dose rates calculated in this section provides sufficient inputs to permit the dose calculation for each worker in the emplacement and retrieval crew. The annual doses to each crewmember are calculated using [Equation 1](#) and are presented in [Table 7](#).

The calculations, using design basis waste package dose rates, indicate that each of the two primary locomotive operators (W1/W2) would receive a maximum dose of 1,780 mrem/yr, which is slightly lower than the 1,890 mrem/yr to the two secondary locomotive operators (W3/W4). Using a scaling factor of 5:1 for design basis to average waste package dose rates under axial geometry exposure conditions ([Assumption 4.2.15](#)), the doses to the primary (W1/W2) and secondary (W3/W4) locomotive operators would be 360 and 380 mrem/yr, respectively.

Exposure times, occupancy, and dose rates to workers during retrieval operations would be similar (but in reverse order of steps) to those calculated for emplacement operations. There would also be a reduction in the dose rates resulting from the radioactive decay of the waste package contents during the storage period.

6.1.2 Collective Worker Doses – Emplacement or Retrieval Operations

The annual collective dose to emplacement or retrieval workers is the sum of the total individual worker doses in each crew listed in [Table 7](#), and is calculated using [Equation 3](#). A single four-worker emplacement or retrieval crew would receive a maximum annual collective dose calculated as $(1,780 + 1,780 + 1,890 + 1,890)/1000$, or 7.3 person-rem/yr. This is doubled to 15 person-rem/yr for the two shifts needed to accommodate a throughput of 600 waste packages per year ([Assumption 4.2.11](#)). Using a scaling factor of 5:1 for design basis to average waste package dose rates under axial geometry exposure conditions ([Assumption 4.2.15](#)), the collective doses, per crew and per annual throughput, would be 1.5 and 2.9 person-rem/yr, respectively.

Table 7. Design Basis Annual Doses to Individual Emplacement Crew Workers

Step [A]	W1/W2 Exposure Duration (hr) [B]	W3/W4 Exposure Duration (hr) [C]	W1/W2 Dose Rate (mrem/hr) [D]	W3/W4 Dose Rate (mrem/hr) [E]	Number of Operations (yr ⁻¹) [F]	W1/W2 Dose (mrem/yr) [G]	W3/W4 Dose (mrem/yr) [H]
1-6a	N/A	N/A	N/A	N/A	300	0	0
6b	0.1	N/A	2.5	N/A	300	75	0
7a,b	0.5	0.5	2.5	3.7	300	375	557
8	0.1	0.1	2.5	2.5	300	75	75
9a	0.55	0.55	2.5	2.5	300	412	412
9b	0.30	0.30	3.4	3.4	300	313	313
10	0	0	5.0	5.0	300	0	0
11	0.5	0.5	2.5	2.5	300	375	375
12	0	N/A	5.0	N/A	300	0	0
13-28	N/A	N/A	N/A	N/A	300	0	0
29	0.1	0.1	2.5	2.5	300	75	75
30	N/A	N/A	N/A	N/A	300	0	0
31a	0.30	0.30	0.92	0.92	300	84	84
31b	N/A	N/A	N/A	N/A	300	0	0
Total	2.5	2.4	N/A	N/A	300	1,780	1,890

Column [A]: Steps described in [Section 4.1.1](#), with some refinements (a, b steps) explained in [Section 6.1.1](#).

Columns [B], [C]: From [Table 3](#) (Number of Workers) and [Table 4](#) (Exposure Duration), except [Steps 9a, 9b](#), and [31a](#), which were calculated in [Section 6.1.1](#).

Columns [D], [E]: [Assumption 4.2.3](#) ([Step 7b](#)), [Assumption 4.2.4](#) ([Steps 8, 9a, and 11](#)), and [Assumption 4.2.5](#) ([Step 29](#)); all others calculated in [Section 6.1.1](#).

Column [F]: [Assumption 4.2.11](#).

Column [G] = [B] × [D] × [F].

Column [H] = [C] × [E] × [F].

N/A: Not applicable to this step for reasons provided in [Tables 3](#) and [4](#).

Miscellaneous Totals: Only the time spent by workers in radiation fields is included and the number of operations is the same for all steps. Totals for Columns [G] and [H] are for [Steps 1-31](#) and apply individually to each of the two workers (W1/W2 or W3/W4) represented in each column.

6.2 MAINTENANCE WORKER DOSES

Annual doses to individual emplacement and retrieval workers are calculated in [Section 6.2.1](#). These doses are then summed in [Section 6.2.2](#) to calculate the collective dose to this group of workers.

6.2.1 Individual Worker Doses – Maintenance Operations

The anticipated types of subsurface maintenance operations are described in [Section 3.2](#). The required number of maintenance workers, and the duration and frequency of each maintenance operation, is described in [Assumption 4.2.12](#), while dose rates at each maintenance location are listed in [Assumption 4.2.13](#).

As was the case with emplacement and retrieval operations, some workers will incur doses during their transit past filled emplacement drifts en route to the maintenance location. The

distances and mean dose rates from this transit are calculated in a manner similar as was conducted for emplacement and retrieval workers ([Section 6.1.1](#)).

For each operation involving ventilation, electrical, or mechanical system maintenance, the most conservative dose estimate would result from transit through the entire length of Emplacement Panel 3, which requires going past a total of 45 turnouts on the east and west sides of the access route ([Assumption 4.2.6](#)). The average dose rates through this length of repository are the same as calculated in [Section 6.1.1](#). However, since the support vehicle is assumed to operate at twice the speed of the waste package transporter ([Assumptions 4.2.9](#) and [4.2.10](#)), transit times and doses would be 50 percent lower. In [Section 6.1.1](#), the product of transit time and average dose rates resulted in a dose of 0.28 mrem to each emplacement worker ([Step 31a](#)). The dose to each maintenance worker would be half this value in each direction, for a total round-trip dose of 0.28 mrem per maintenance operation.

Combining the applicable assumptions from [Section 4.2](#) with the transit doses calculated in this section provides sufficient inputs to permit the dose calculation for each worker in a maintenance crew. The individual doses to each crewmember are calculated using [Equation 2](#) and are presented in [Table 8](#).

Table 8. Design Basis Annual Doses to Individual Maintenance Crew Workers

Maintenance Operation [A]	Duration of Operation (hr) [B]	Operation Dose Rate (mrem/hr) [C]	Dose per Operation (mrem) [D]		Transit Dose per Operation (mrem) [E]	Number of Annual Operations [F]	Annual Dose (mrem/yr) [G]
Ventilation Door [1] @	2	10	20	23 (sum)	0.28	10	233
Ventilation Main [2] @	1.2	2.5	3				
Electrical	3.5	10	35		0.28	12	423
Mechanical (Rail)	8	2.5	20		0.28	5	101
Ground Control	3.2	2.5	8		Included as part of operation	2	16

Column [A]: Table 5, Column [A].

Column [B]: Table 5, Column [C].

Column [C]: Table 6, Column [B].

Column [D] = [B] x [C], except Ventilation Total: [D (sum)] = [D1] + [D2].

Column [E]: Calculated in Section 6.2.1 or part of operations per Assumption 4.2.12.

Column [F]: Table 5, Column [D].

Column [G] = ([D]+ [E]) x [F], except Ventilation: [G] = ([D (sum)] + [E]) x [F].

N/A: Not applicable to Ventilation Total.

Using a scaling factor of 5:1 for design basis to average waste package dose rates under axial geometry exposure conditions ([Assumption 4.2.15](#)), the doses to individual ventilation, electrical, mechanical, and ground control maintenance workers would be 47, 85, 20, and 3.2 mrem/yr, respectively.

6.2.2 Collective Worker Doses – Maintenance Operations

The annual collective dose to maintenance workers is the sum of the individual worker doses in each crew and is calculated using [Equation 3](#). Using the individual doses calculated in

[Section 6.2.1](#) and crew sizes listed in [Table 5](#) ([Assumption 4.2.12](#)), the annual collective dose for each maintenance operation is calculated and presented in [Table 9](#).

Table 9. Design Basis Annual Collective Doses for Subsurface Maintenance Operations

Maintenance Operation [A]	Crew Size [B]	Individual Dose (mrem/yr) [C]	Collective Dose (person-rem/yr) [D]
Ventilation	3	233	0.70
Electrical	1	423	0.42
Mechanical	3	101	0.30
Ground Control	1	16	0.016
Total	8	N/A	1.4

Column [A]: [Table 5](#), Column [A].

Column [B]: [Table 5](#), Column [B].

Column [C]: [Table 8](#), Column [G].

Column [D] = [B] x [C]/1000.

Using a scaling factor of 5:1 for design basis to average waste package dose rates under axial geometry exposure conditions ([Assumption 4.2.15](#)), the average collective doses to ventilation, electrical, mechanical, and ground control maintenance workers would be 0.14, 0.085, 0.061, and 0.0032 person-rem/yr, respectively.

7. RESULTS

Individual and collective doses to subsurface repository workers are estimated using the methodology and equations described in [Section 3](#), design parameters listed in [Section 4.1](#), assumptions defined in [Section 4.2](#), software described in [Section 5](#), and calculations performed in [Section 6](#). The parameters used in the dose calculations are supported by appropriate and conservative input data and assumptions. The calculated worker doses, summarized in [Table 10](#), represent reasonable maximum and average results compared with the inputs used to derive them. The results are, therefore, suitable for the intended use. Uncertainties in the results are identified primarily by the use of input values related to design basis and average dose rates from the emplaced and transported waste packages. This uncertainty is evident in the range of results presented in [Table 10](#). Additional uncertainties regarding the duration of operations, number of workers, and waste throughputs are not easily quantifiable, but the selected inputs are judged to be representative of conservative conditions. The impacts of some of these additional uncertainties and conservative input values are presented in [Section 7.3](#).

7.1 CONSIDERATION OF INTERNAL DOSES

The *Preliminary Consequence Analysis for License Application* (BSC 2003f, [Table II-15](#)) indicates that total doses to maximally exposed subsurface workers from inhalation of airborne radionuclides would be less than 2 mrem/yr. This is well below the external doses listed in [Table 10](#) of this calculation. Therefore, the maximum annual TEDE for subsurface workers can be approximated by the total annual external dose to each worker reported in [Sections 6.1.1](#) and [6.2.1](#).

Table 10. Summary of Individual and Collective Doses to Subsurface Facility Workers

Number of Workers/ Operation or Shift [A]	Worker ID [B]	Design Basis Individual Dose (mrem/yr) [C]	Average Individual Dose (mrem/yr) [D]	Shifts [E]	Design Basis Collective Dose (person-rem/yr) [F]	Average Collective Dose (person-rem/yr) [G]
Four Emplacement/ Retrieval Workers per Shift (Eight per Operation)	W1	1,780	360	2	15	2.9
	W2					
	W3	1,890	380			
	W4					
Three Ventilation Maintenance Workers per Operation	W1	233	47	1	0.70	0.14
	W2					
	W3					
One Electrical Maintenance Worker	W1	423	85	1	0.42	0.085
Three Mechanical Maintenance Workers per Operation	W1	101	20	1	0.30	0.061
	W2					
	W3					
One Ground Control Maintenance Worker	W1	16	3.2	1	0.016	0.0032
Total	16	N/A	N/A	N/A	16	3.2

Columns [A] and [B]: Assumptions [4.2.1](#) (Emplacement/Retrieval) and [4.2.12](#) (Maintenance).

Columns [C] and [D]: Sections [6.1.1](#) (Emplacement/Retrieval) and [6.2.1](#) (Maintenance).

Column [E]: Assumptions [4.2.11](#) (Emplacement/Retrieval) and [4.2.12](#) (Maintenance).

Columns [F] and [G]: Sections [6.1.2](#) (Emplacement/Retrieval – Total for 2 Shifts) and [6.2.2](#) (Maintenance).

NOTE: Total number of workers accounts for two shifts of four emplacement/retrieval workers.

7.2 COMPARISON WITH REGULATORY LIMITS

All the annual individual doses calculated in [Section 6](#) are a factor of 2.6 or more times lower than the U.S. Nuclear Regulatory Commission regulatory limit of 5 rem/yr TEDE ([Section 4.3](#)). Since all the radiation fields used in this calculation affect the workers' whole body, and do not preferentially irradiate the skin, lens of the eye, extremities, or specific organs, the TEDE limit is bounding. Therefore, all subsurface operations identified in this calculation comply with applicable regulations limiting occupational exposures.

These doses have been calculated using radiation fields or design criteria applicable to design basis waste packages. This is a very conservative approach when operations involving large numbers of waste packages are considered. The result is higher exposures to personnel than would be incurred from the same number of average waste packages. Therefore, there is an adequate margin of safety in these calculations to provide assurance that the annual occupational dose limits would not be exceeded in any year from these operations.

7.3 COMPARISON WITH ALARA GOAL

The individual doses to maintenance crew workers, including doses calculated using dose-rate criteria applicable to design basis waste packages, are all below the 500-mrem/yr ALARA goal ([Section 4.4](#)). Therefore, no additional ALARA considerations are required for such workers unless they are likely to be exposed to radiation from other maintenance activities not considered in this calculation.

The 1,890 mrem/yr individual dose to emplacement and retrieval workers W3 and W4, calculated using dose-rate design criteria applicable to design basis waste packages, exceeds the ALARA goal specified in [Section 4.4](#) by a factor of 3.8. However, assuming average rather than design basis waste packages as the basis for these calculations ([Assumption 4.2.15](#)) reduces the calculated doses to less than the 500-mrem/yr individual ALARA goal.

In addition, the use of maximum travel distances and maximum throughput contributes to the conservatism in these calculations. For example, the dose contributions from the turnouts are highly dependent on the location of the active emplacement area in each panel. A projected maximum throughput of 526 waste packages per year in 2022 and 2023 (Cloud 2003, [Table 4](#)) would result in annual doses to emplacement workers approximately 12 percent lower than doses calculated using a throughput of 600 waste packages per year ([Assumption 4.2.11](#)). The annual waste package throughput (and the calculated collective doses) would be lower in other years. In addition, fewer filled drifts early in the emplacement phase would result in lower doses to maintenance workers since annual doses are assumed to peak towards the end of the emplacement operations, when most drifts are full.

Finally, if only a two-person crew (rather than a four-person crew, per [Assumption 4.2.1](#)) performs subsurface emplacement and retrieval operations (one operator per locomotive), this would reduce the collective dose to emplacement and retrieval workers by almost 50 percent.

While a formal ALARA evaluation for the subsurface operations considered in this calculation is outside the scope of this calculation, some of the considerations presented here may be applied as part of such an evaluation.

8. REFERENCES

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8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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ATTACHMENT I

DOSE-RATE REDUCTION FACTORS FOR THE AVERAGE SPENT NUCLEAR FUEL

This attachment presents an estimation of dose-rate reduction factors between a waste package loaded with the design basis pressurized water reactor (PWR) spent nuclear fuel (SNF) and one with the average PWR SNF, and between a waste package loaded with the bounding PWR SNF and one with the average PWR SNF. The dose rates outside a 21-PWR waste package are obtained from the *Dose Rate Calculation for 21-PWR Waste Package* (BSC 2003g). The nuclear characteristics of the three spent fuel types are described in BSC 2003e (Section 5.1.4). The reduction factors are derived separately for the radial, top, and bottom directions of a 21-PWR waste package. [Table I-1](#) summarizes the dose rates and reduction factors for a 21-PWR waste package separately loaded with one of the three spent fuel types.

Table I-1. Dose Rates and Reduction Factors for a 21-Pressurized Water Reactor Waste Package

Radial Direction					
Location	Dose Rate (rem/hr) ^a			Reduction Factor	
	Design Basis SNF [A]	Average SNF [B]	Bounding SNF [C]	Bounding/ Average [D]	Design Basis/ Average [E]
Surface [1]	5.83E+02	1.93E+02	1.38E+03	7.15	3.02
1-meter [2]	2.23E+02	7.26E+01	5.22E+02	7.19	3.07
2-meter [3]	1.38E+02	4.42E+01	3.23E+02	7.31	3.12
Average [4]	-	-	-	7.22	3.07
Top Direction					
Location	Dose Rate (rem/hr) ^b			Reduction Factor	
	Design Basis SNF [A]	Average SNF [B]	Bounding SNF [C]	Bounding/ Average [D]	Design Basis/ Average [E]
Surface [1]	4.06E+02	6.02E+01	8.60E+02	14.29	6.74
1-meter [2]	1.16E+02	1.87E+01	2.48E+02	13.26	6.20
2-meter [3]	5.87E+01	1.03E+01	1.26E+02	12.23	5.70
Average [4]	-	-	-	13.26	6.22
Bottom Direction					
Location	Dose Rate (rem/hr) ^b			Reduction Factor	
	Design Basis SNF [A]	Average SNF [B]	Bounding SNF [C]	Bounding/ Average [D]	Design Basis/ Average [E]
Surface [1]	1.30E+03	2.21E+02	2.80E+03	12.67	5.88
1-meter [2]	3.69E+02	6.47E+01	8.02E+02	12.40	5.70
2-meter [3]	1.70E+02	3.08E+01	3.70E+02	12.01	5.52
Average [4]	-	-	-	12.36	5.70

Column [D] = [C]/[B], except [D4] = Average ([D1]:[D3])

Column [E] = [A]/[B], except [E4] = Average ([E1]:[E3])

^aBSC 2003g, Tables 6.1-7, 6.1-8, 6.1-9, 6.2-2, 6.2-3, 6.2-4, 6.3-2, 6.3-3, and 6.3-4. The dose rates of Segment 6 in the tables were chosen.

^bBSC 2003g, Tables 6.1-10, 6.2-5, and 6.3-5

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